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Inspection Based Evaluation of a Danish Road Bridge

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Abstract
In this paper it is shown how an inspection-based evaluation of a Danish road bridge may be performed using the BRIDGE1 and BRIDGE2 bridge management systems produced within the EC-supported research programme "Assessment of Performance and Optimal Strategies for Inspection and Maintenance of Concrete Structures using Reliability Based Expert Systems".

Introduction
Most of the reinforced concrete bridges built in Europe and in other parts of the world in the past seventy years were designed on the basis of a general belief among engineers and scientists that the durability of the composite material could be taken for granted. Although a vast majority of reinforced concrete bridges have performed satisfactorily during their service life, numerous instances of distress and deterioration have been observed in such structures in recent years. The causes of deterioration of reinforced concrete bridges are often related to durability problems of the composite material. One of the most important deterioration processes which may occur in reinforced concrete bridges is reinforcement corrosion, caused by chlorides present in de-icing salts and/or carbonation of the concrete cover zone.

Although the phenomenon of reinforcement corrosion is fairly well understood, rational decisions about cost-effective bridge designs, optimum strategies for inspection, maintenance and repair are hampered by the absence of comprehensive data on the structural performance of deteriorated concrete elements.

Inspection-based evaluation of concrete bridges has been investigated in detail in the above-mentioned EC-supported research project, see e.g. (Thoft-Christensen & Hansen, 1993) and (de Brito et. al. 1997). The research in the research project aimed to overcome the above-mentioned shortcoming by developing procedures for

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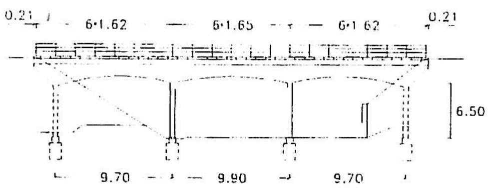
assessing the influence of reinforcement corrosion on the structural performance of reinforced concrete members. The experimental work was carried out on reinforced concrete beams and columns, which were subjected to accelerated reinforcement corrosion. Special emphasis was placed upon the evaluation of the bond strength at the steel/concrete interface. Different repair materials were examined from the view-point of performance under renewed corrosion attack. Structural analysis and reliability analysis techniques were applied to the results of the study, and simple models for predicting the residual strength of the corroded beams were produced. Such information was successfully incorporated in improved stochastic modelling of the deterioration to formulate optimal strategies for inspection and maintenance of deteriorated reinforced concrete bridges using a reliability-based expert system.

Description of the Bridge

The bridge used in this case study is a Danish road bridge (no: 153-0002) in the town Lov. It is a reinforced concrete bridge crossing over the railway Næstved-Storstrøm. It was built in 1921 and enlarged in 1936 to a double width by building a similar new bridge parallel to the old one. The bridge is a three-span structure, see figure 1, with a total length of 33 m. The superstructure is supported at the ends and by two columns. The midspan is 9.9 m, and the side spans are 9.7 m each. The total width of the bridge is 9.5 m.



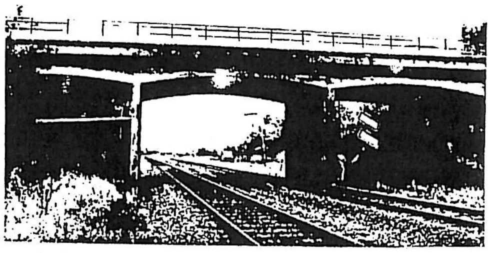


Figure 1. Front of Bridge.

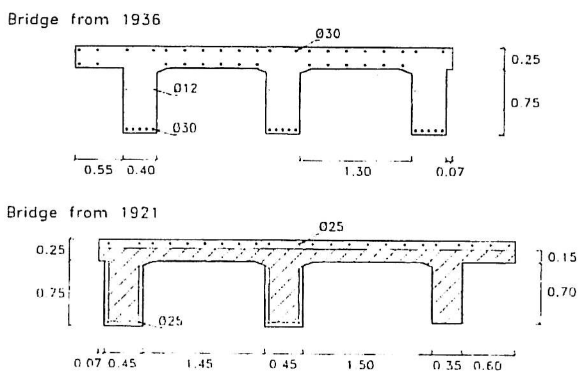


Figure 2. Cross-section of the bridge (midspan) . Stirrups are not shown.

In connection with the enlargement of the bridge in 1936 die casting repair was performed on some parts of the old bridge and reinsulation of the superstructure was made. Further, some of the columns on the old part of the bridge were strengthened. The bridge is a beam-slab bridge with the cross-section shown in figure 2. In figures 2 and 3 the hatched part of the bridge is the original reinforced concrete, where the reinforcement is not known.

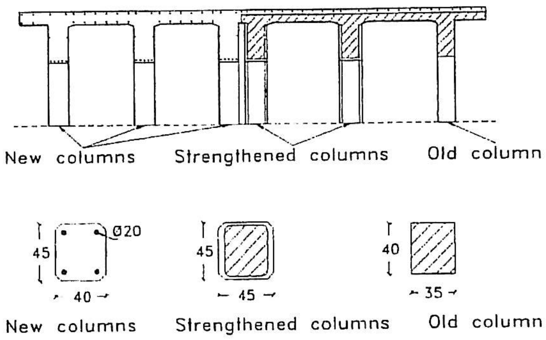


Figure 3. Dimensions of the columns. Stirrups are not shown.

The bridge is designed for a load case consisting of a 20 t roller and 500 kg/m^2 live load according to the Danish design rules of 1930 for reinforced concrete bridges. The compressive strength of the concrete is 30 N/mm^2 for the new part of the bridge. The compressive strength of the concrete of the old part of the bridge is not known. The yield stress of the reinforcement is not known. Therefore, in this study the yield stress for the plain bars is assumed to be 225 N/mm^2.

Inspection Test Results

In December 1988 a detailed inspection of the bridge was performed. The load-bearing part of the superstructure and the intermediate columns were inspected. The detailed inspection contained:

- Tests of the corrosion of the reinforcement by EKP and chipping off samples of concrete.
- Measuring of the chloride content and carbonation depth in the concrete at selected places.
- Analysis of the micro-structure of the concrete.
- Assessment of the damage influence on the load capacity.
- Suggestions for the repair of the bridge.

The tests were performed on the slab, on the beams and on the columns. Tests included: measurements of chloride content, chipping off concrete, core samples and EKP-tests. Further visual observations were made. Many cracks were found visually. Most of the cracks were in the older part of the bridge from 1921. Further, it was observed that open cracks only appear where die casting repair was not performed. Closed cracks were mainly observed where die casting repair was performed. The cover of the stirrups is in general 10-15 mm. However, the main reinforcement has a 40 mm cover.

EKP-tests were made at several places. The EKP measurements show that the resistance is "medium high". This indicates that the concrete has a medium high resistance probably because there is a relatively low humidity content and a small concentration of decomposed salts, e.g. chloride. This means that the conductivity in the concrete is not considered to be large. The measured potentials show:

- The potentials measured show lower potentials on the part from 1921 than on the part from 1936. This indicates, as expected, that the corrosion activity is higher on the older part of the bridge.
- There are no significant differences between the potentials measured on the old columns whether die casting repair has been performed or not. The absolute potentials show medium high values indicateing that there is no corrosion activity.
- In some areas the potentials of the beams are a little smaller than those measured in the slab. This is not a surprise because many closed cracks were visually observed in such areas. Thereby oxygen and humidity have easier access, which reduces the potential. The probability for corrosion in the future is higher in these areas than usual.

In some areas concrete was chipped off in beams and columns. In non-damaged areas no carbonation was found. At several places with porous and delaminated concrete, considerable corrosion activity was found on the reinforcement and the stirrups and the carbonation was measured to 10-20 mm. Cover damage was observed at several places.

The content of chloride in the concrete was measured at several places at three depths 0-20 mm, 20-40 mm, and 40-60 mm. Further measurements were performed for the slabs at the depth 100-120 mm. The chloride content varied between 0 and 0.03 %. At the reinforcement level the chloride content was only 0-0.1 %, which is not critical.

Two sample cores of concrete were investigated. The first is from an area of the old part of the bridge where open cracks were observed. The second core is from an intact area of the new part of the bridge.

The results for the core from the old part of the bridge from 1921 are: Some weak alkali-aggregate reactions were observed, the concrete is relatively homogeneous and well compressed without macro defects, the content of compound cement grains is irregularly distributed in the paste, the water/cement ratio is between 0.35 and 0.50, the paste is full of micro-cracks, the concrete contains reactive stones and sand, the paste is inhomogeneous, perhaps because of the distribution of the compound cement grains, the polished thin sections have a general carbonation of 10 mm.

The results for the core from the part of the bridge from 1936 are: Some weak alkali-aggregate reactions and one strong reaction were observed, the concrete is relatively homogeneous and well compressed without macro defects, the paste is inhomogeneous on the first 20-30 mm from the surface and hereafter it is less inhomogeneous, the paste has micro-cracks, the concrete contains reactive stones and sand, the polished thin sections have a general carbonation depth of about 2 mm, but also a crack carbonation depth of 15 mm in a fine crack.

The conclusions of the detailed inspection are:

- At several places strongly corroded reinforcement bars were found. Especially corrosion was found on such parts of the bridge from 1921, where die casting repair had not been performed.
- The reason for the strong corrosion in those areas is carbonation, where the basic environment of the reinforcement is neutralised because of carbondioxide penetration from the surface of the concrete. The carbonation depth in those areas was measured from about 15 mm to past the level of the main reinforcement.
- In such areas of the bridge from 1921 where die casting repair had been performed and on the part of the bridge from 1936 the measured carbonation depths were less than 5 mm. Therefore, the reinforcement bars are still protected there. An exception is column 50, where a strong corrosion of the reinforcement was observed.
- Although the general carbonation of the bridge from 1936 was small, it must be noted that the analysis of the structure of the concrete showed that the carbonation depth measured along some fine cracks was 15 mm. The carbonation may therefore in the future cause corrosion of the reinforcement in these places.
- Locally the concrete was porous. Therefore, the carbonation can be expected to run faster.
- The chloride content was not serious.
- The closed cracks were assumed to be due to shrinkage of the concrete since closed cracks were only in areas where die casting repair was performed.
- It is recommended that all the observed damages are repaired as soon as possible. However, also for areas where there is a great risk of initiation of reinforcement corrosion, precautions are recommended.

BRIDGE1 and BRIDGE2 Modules

Advanced bridge management systems have been discussed by (Thoft-Christensen, 1995). As an example of an advanced management system the BRIDGE1 and BRIDGE2 systems are presented in detail in the same paper. Therefore, only a brief presentation is given here.

The expert system module BRIDGE1 is used on the bridge site during an inspection. This expert system module contains useful information concerning the bridge inspected and the defects observed. The information includes: general information about the bridge, appropriate diagnostic methods for each defect, probable causes for each defect, and other defects related to a defect.

The general information about the bridge stored in the database for the selected bridge can be reviewed. The database contains information about bridge site, design, budget, traffic, strength, load, deterioration, factors that model the costs, and the cross-sections entered for the bridge.

New cross-sections can be entered for the selected bridge. The information stored in the database for each cross-section contains: cross-section identification, geometry of cross-section (detailed description of the reinforcement layers for cross-sections of the deck), failure mode, and load data. Technical support can be provided for a defect. The technical support includes a list of diagnostic methods that can be used to observe a selected defect. The technical support also includes a list of probable causes of a selected defect. A list of defects associated with the selected defect is also included. This list is very useful since the probable associated defects can be reviewed if the selected defect is observed. Measures for the correlations of the selected defect and the related defects are shown.

The expert system module BRIDGE2 is used to make a detailed analysis of the bridge after an inspection when testing has been performed in the laboratory. New bridges and cross-sections can be entered into the database and existing bridges and cross-sections can be edited. For the bridges in the database the following options are available: review provisional defect reports, enter inspection results, estimate the reliability index, plan maintenance work and estimate costs, plan structural repair work and estimate costs, and review the agenda of inspection for one bridge or all bridges. Further, the database can be updated after repair.

New bridges can be entered and existing bridges can be edited. The general information about the bridges stored in the database contains information about: bridge site, design, budget, traffic, strength, load, deterioration, factors that model the costs, and the cross-sections entered for each bridge.

After an inspection the provisional defect reports recorded at previous inspections can be reviewed. A description of the detected defects and measurements of diagnostic methods can be entered. After repair the databases can be updated.

The reliability index for the bridge can be estimated by the integrated FORTRAN program RELIAB. The reliability index, when no inspection results are taken into account, and the the updated reliability index, when all inspections performed for the bridge are taken into account, can be estimated.

The following submodules are integrated into BRIDGE2:

- BRIDGE2(M) is the maintenance/small repair submodule. This submodule assists in selecting the maintenance work and repair of minor structural defects to be performed and estimates the maintenance costs. The defects are rated based on the defect classification in terms of rehabilitation urgency, importance of the stability of the structure, and affected traffic recorded during the inspection.
- BRIDGE2(I) is the inspection strategy submodule. This submodule assists in the decision whether a structural assessment is needed before the next periodic inspection. The decision made in BRIDGE2(I) is mainly based on the updated reliability index for the bridge calculated by RELIAB. If the value of the updated reliability index for the bridge is acceptable then each of the defects detected at the latest periodic inspection and the combination of defects are investigated.

Based on expert knowledge it is investigated whether a defect or combinations of defects from a structural point of view require a structural assessment.

- BRIDGE2(R) is the repair submodule. This submodule is always used after a structural assessment. It assists in selecting the optimal structural repair technique (including no repair) to be performed, when the repair should be performed, and the number of repairs in the remaining lifetime of the bridge. Further, the expected benefits minus costs are estimated. The repair plan is optimized based on a cost-benefit analysis by the FORTRAN program INSPEC.

Inspection-Based Reliability Assessment

When inspection results are obtained, the reliability indices for single failure modes and for the system (the bridge) can be updated using RELIAB. Assume that e.g. the chloride content is measured to be smaller than some value at a given depth. This inspection result can then be modelled as an inequality I of the form

$$I = \{H \leq 0\} \tag{1}$$

where H is the event (safety) margin. The probability of failure P_f of a single element with safety margin M can then be updated by

$$\begin{aligned} P_f^U &= P(M \leq 0 | H \leq 0) \\ &= \frac{P(M \leq 0 \cap H \leq 0)}{P(H \leq 0)} \end{aligned} \tag{2}$$

It is seen from (2) that the updated failure probability is simply estimated by calculating the failure probability of a single element and the failure probability of a parallel system.

If more than one inequality event are available then the updating can be performed in a similar way. Let H_i be the event margin for inequality i, then the updated failure probability can be calculated by

$$\begin{aligned} P_f^U &= P(M_1 \leq 0 \cap ... \cap M_m \leq 0 | H_1 \leq 0 \cap ... \cap H_N \leq 0) \\ &= \frac{P(M_1 \leq 0 \cap ... \cap M_m \leq 0 \cap H_1 \leq 0 \cap ... \cap H_N \leq 0)}{P(H_1 \leq 0 \cap ... \cap H_N \leq 0)} \end{aligned} \tag{3}$$

All the probability calculations are in this way reduced to calculation of parallel systems. Similar expressions can be derived for equality events

$$I = \{H = 0\} \tag{4}$$

The probability of failure P_f of a single element with safety margin M can in this case be updated by

$$
\begin{aligned}
P_f^U &= P(M \le 0 | H = 0) \\
&= \frac{P(M \le 0 \cap H = 0)}{P(H = 0)} \\
&= \frac{\frac{\partial}{\partial x} P(M \le 0 | H - x < 0)}{\frac{\partial}{\partial x} P(H - x \le 0)}
\end{aligned} \tag{5}
$$

In the case of N inequality events, the updated failure probability can be calculated by

$$
\begin{aligned}
P_f^U &= P(M_1 \le 0 \cap ... \cap M_m \le 0 | H_1 = 0 \cap ... \cap H_N = 0) \\
&= \frac{P(M_1 \le 0 \cap ... \cap M_m \le 0 \cap \; H_1 = 0 \cap ... \cap H_N = 0)}{P(H_1 = 0 \cap ... \cap H_N = 0)} \\
&= \frac{\frac{\partial^N}{\partial x_1 ... \partial x_N} P(M \le 0 \cap H_1 - x_1 \le 0 ... \cap H_N - x_N \le 0)}{\frac{\partial^N}{\partial x_1 ... \partial x_N} P(H_1 - x_1 \le 0 ... \cap H_N - x_N \le 0)}
\end{aligned} \tag{6}
$$

The derivatives in (5) and (6) are evaluated at $x = 0$ and $x_1 = x_2 = ... = x_N$, respectively.

Similar expressions can be derived for series systems and parallel systems. If both inequality and equality events are available, then updating can be performed by generalizing the equations shown above.

Stochastic Models for Inspection

In this paper to types of uncertainty related to inspection are considered.

- The first is related to the uncertainty (reliability) of an inspection method, i.e. how good is an inspection technique to detect a defect if a defect is present, and what is the risk that the inspection method indicates a defect when there is no defect (false alarm).
- The second type of uncertainty is related to the measurement uncertainty when a detected defect is being quantified.

The inspection method as well as the inspection team is important for the effectiveness of an inspection. The reliability of an inspection can in some cases be modelled by a so-called pod (probability of detection) curve defined by

$$
p(\mathrm{a}) = P(\text{detection of defect} \,|\, \text{defect size } = \mathrm{a}) \tag{7}
$$

A defect should here be considered as the quantity measured, e.g. the measured potentials using "half-cell potential" testing. The pod is also equal to the distribution function of the smallest detectable defect size. The probability of detecting a defect highly depends on the conditions on which the inspection is performed. Inspections performed in a laboratory are usually much more reliable than field inspections. Therefore, pod curves obtained from laboratory test conditions must be modified in order to model field inspections. A number of pod curves have been suggested on an empirical basis. A commonly used form of the pod curve is an exponential function

$$p(a) = \begin{cases} 0 & \text{for } 0 < a < a_0 \\ \Delta(1-(1-\delta)\exp(-\lambda(a-a_0))) & \text{for } a_0 \leq a \end{cases} \tag{8}$$

where Δ is a parameter $(\delta < \Delta \leq 1)$ which gives the probability of detecting a very large defect. δ is a parameter $(0 \leq \delta < \Delta)$ which gives the probability of detecting a very small defect. a_0 is the minimum defect size below which a defect cannot be detected. λ is a parameter depending on the inspection effectiveness and the inspection method.

If a crack (or defect) is detected then the measurement of the actual defect can be performed. Errors in connection with this measurement depend on the measurement technique used. The two most common probabilistic models of measurement errors are a simple additive and a simple multiplicative model. The additive model assumes that the measured defect size a_m can be modelled by

$$a_m = a + \varepsilon \tag{9}$$

where a is the (correct) defect size and ε is a normally distributed random variable modelling the measurement error. ε is assumed to have zero mean and a standard deviation, which depends on the measurement technique. The multiplicative model assumes that the measured defect size a_m can be modelled by

$$a_m = a\delta \tag{10}$$

where a is the (correct) defect size and δ is a lognormally distributed random variable modelling the measurement error. δ is assumed to have unit mean and a standard deviation which depends on the measurement technique.

As an example, consider the "half-cell potential" test for detection of corrosion in reinforcement steel. Let C model the event that corrosion is active and let V model the measured potential, then the probability that corrosion is active given a measured potential v is given by

$$p_C(v) = P(C \mid V = v) \tag{11}$$

In BRIDGE2 the function shown in figure 4 for $p_C(v)$ is used.

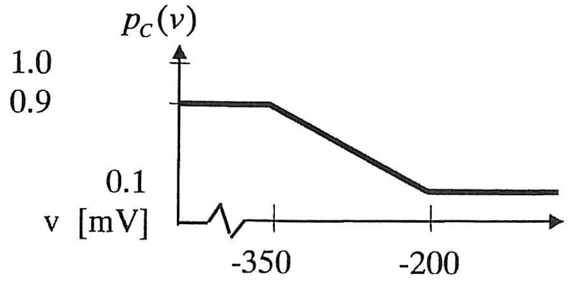


Figure 4. Empirical model for $p_C(v)$.

The measurement of the potential v is subjected to some uncertainty. Based on a literature survey it is chosen in BRIDGE2 to model the measured potential by

$$v_m = Z_m + v \tag{12}$$

where Z_m is a normally distributed stochastic variable with the expected value 0 and a standard deviation of 200 mV. By including the measurement uncertainty the probability of active corrosion is changed to

$$P(C|V = v) = \int_{-\infty}^{\infty} P(\text{active corrosion given measured potential is } 200z_v + v)\varphi(z_v)dz_v \tag{13}$$

where φ is the standard normal stochastic variable and v is measured in mV.

Let failure be modelled by the event F, then the failure probability can be updated by

$$\begin{aligned} &P(F|V = v) = \\ &P(F|C \cap V = v)P(C|V = v) + P(F|\bar{C} \cap V = v)P(\bar{C}|V = v) \quad = \\ &P(F|C \cap V = v)P(C|V = v) + P(F|\bar{C} \cap V = v)(1 - P(C|V = v)) \end{aligned} \tag{14}$$

Reliability Assessment of the Danish Bridge

The reliability of the bridge is estimated before and after the inspection using the inspection modelling principles outlined above. Two failure modes related to two cross-sections in the deck are investigated in the analysis and 3 inspection results are included. The results using RELIAB are shown in figure 5. It is seen from figure 5 that the (systems) reliability index is estimated as 2.38 without using the information obtained during the inspection. The reliability index is increased to 2.86 if the inspection results are included in the assessment using the procedure explained in this paper.

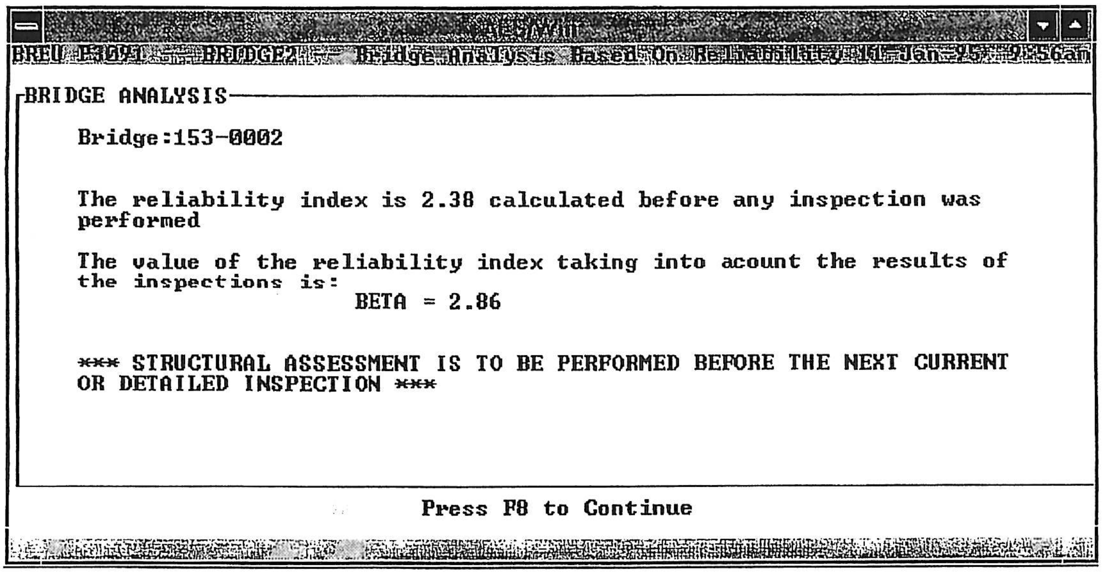


Figure 5. Reliability Analysis of the Bridge.

Conclusions

Inspection-based evaluation of a Danish road bridge is presented in this paper. The bridge is a reinforced concrete bridge crossing over a railway. It was built in 1921 and enlarged in 1936 to a double width. It is a three span structure with a total length of 33 m.

A detailed inspection of the bridge was performed in 1988. The inspection included testing of the corrosion of the reinforcement and the carbonation depth, measurements of the chloride content, and micro-structure analysis. Strongly corroded reinforcement bars due to carbonation were found at several places.

The expert bridge management systems BRIDGE1 and BRIDGE2 are briefly presented with special emphasis on reliability assessment based on inspection results. It is shown how updated failure reliability can be calculated. As an example the reliability of the above-mentioned bridge before and after the inspection is assessed.

Acknowledgement

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References

de Brito, J., F.A. Branco, P. Thoft-Christensen & J. D. Sørensen: *An Expert System for Concrete Bridge Management,* Engineering Structures, Vol. 19, 1997, pp. 519-526.

Thoft-Christensen, P. & H.I. Hansen: *A Reliability-based Expert System for Bridge Maintenance,* Proc. ICOSSAR'93, Innsbruck, Austria, 1993, pp. 939-946.

Thoft-Christensen, P.: *Advanced Bridge Management Systems,* Structural Engineering Review, Vol. 7, 1995, pp. 151-163.

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